Wood properties of exotic larch grown in eastern Canada and north-eastern United States

by Y. H. Chui[1] and Glenda MacKinnon-Peters[2]

The rapid growth performance of exotic larch such as Japanese larch (*Larix leptolepis* (Sieb. et Zucc) Gord.) and European larch (*Larix decidua* Mill.) has attracted the attention of the forestry sector in eastern Canada and north-eastern United States for lumber and pulp production. While growth performance of these species in North America has been well documented, little is known with regards to their wood properties. The objective of this study was to evaluate the primary lumber grade yields, mechanical properties, fiber length, specific gravity and cold-water soluble extractives of larch from plantations in Maine, Nova Scotia, New Brunswick and Prince Edward Island. Samples were obtained from a Japanese (age 31), three European (age 17, 34 and 63) and one Japanese × European hybrid (age 22-27) larch stands. It was found that the structural grade yields of these species were relatively low because of the influence of knots. The mechanical properties (modulus of rupture and modulus of elasticity) of the mature European larch appeared to be comparable with published data for some native softwood species. Fiber length, specific gravity and cold-water soluble extractive content of all samples were similar to those found for other softwood species which are used for pulp production. Fiber length of the juvenile wood of European larch was significantly shorter than that of mature wood. Extractive content was highest in newly formed heartwood. Contrary to common belief, extractive content in young trees may not be low.

Key words: Japanese larch (*Larix leptolepis* Gord.), European larch (*Larix decidua* Mill.), European × Japanese hybrid (*Larix eurolepis*), Wood properties, Lumber yields

Les performances de croissance rapide de mélèzes exotiques tel le mélèze japonais (*Larix leptolepis* (Sieb. et Zucc) Gord.) et le mélèze européen (*Larix decidua* Mill.) ont attiré l'attention du secteur forestier de l'est du Canada et du nord-est des États-Unis au niveau de la production de bois de sciage et de pâte. Alors que les performances de croissance de ces espèces en Amérique du Nord sont très bien documentées, nous savons très peu de chose sur les propriétés du bois de ces espèces. L'objectif de cette étude était d'évaluer les rendements lors du classement primaire du bois, les propriétés mécaniques, la longueur des fibres, la gravité spécifique et les particules solubles à l'eau froide des mélèzes issus de plantations du Maine, de la Nouvelle-Écosse, du Nouveau-Brunswick et de l'Ile-du-Prince-Édouard. Des échantillons ont été obtenus d'un peuplement de mélèze japonais (âgé de 31 ans), de trois peuplements de mélèze européen (âgés de 17, 34 et 63 ans) et d'un peuplement de mélèze hybride japonais × européen (âgé entre 22 et 27 ans). L'étude a démontré que les rendements en fonction des classes structurales de ces espèces étaient relativement faibles par suite de la présence de noeuds. Les propriétés mécaniques (coefficient de rupture et coefficient d'élasticité) des mélèzes européens mûrs semblaient être comparables aux données publiées pour quelques espèces natives de résineux. La longueur des fibres, la gravité spécifique, et les particules solubles à l'eau froide en fonction du contenu des échantillons étaient semblables aux résultats répertoriés pour d'autres espèces de résineux utilisés dans la production de pâte. La longueur des fibres du bois juvénile du mélèze européen était significativement plus courte que celle du bois produit à maturité. Le plus grand nombre de particules solubles se retrouvaient dans le bois de coeur récemment formé. Contrairement à la croyance populaire, les particules solubles des jeunes arbres peuvent ne pas être en faible quantité.

Mots clés: mélèze japonais (*Larix leptolepis* Gord.), mélèze européen (*Larix decidua* Mill.), hybride européen × japonais (*Larix eurolepis*), propriétés du bois, rendements du sciage

Introduction

In Europe and Asia, the larch genus (*Larix* Mill.) include some important species for lumber and pulp and paper production. In eastern Canada, the only native larch species is tamarack (*Larix laricina* (Du Roi) K. Koch.). Tamarack generally grows on relatively poor sites and therefore has a slow growth rate (Loo-Dinkins *et al.* 1992). The wood of this species is dense, strong and relatively resistant to decay mainly due to its high extractive content in the heartwood (Mullins and McKnight 1981). These wood characteristics are good attributes for utilization as lumber. When the wood is converted into pulp, the high extractive content can cause problems with some pulping processes (Hatton 1986).

[1]Associate Professor Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 6C2.
[2]Research Engineer, Wood Science and Technology Centre, Faculty of Forestry and Environmental Management, University of New Brunswick, Fredericton, New Brunswick, Canada E3B 6C2.

Interest in fast-growing species has led to the initiation of a number of trials of exotic larch species in eastern Canada and north-eastern United States. The major exotic larch species introduced into eastern Canada are Japanese larch (*Larix leptolepis* Gord.), European larch (*Larix decidua* Mill.) and European x Japanese hybrid (*Larix eurolepis*). These faster growing species can produce large volumes of fiber in a relatively short period of time compared with tamarack, but this is achieved at the expense of lower wood specific gravity. Lower specific gravity is usually associated with lower mechanical properties and pulp yield per volume of fiber. On the other hand, there is evidence that the extractive content in fast-grown young trees of these exotic larches is lower compared with tamarack because of the lower percentage of heartwood (Isebrands and Hunt 1975; Isebrands *et al.* 1982; Fowler *et al.* 1988).

While the growth performance of exotic larch species has been well documented (MacGillivaray 1969; Ker *et al.* 1983; Park and Fowler 1983; Fowler 1986; Fowler *et al.* 1988; Loo-Dinkins *et al.* 1992), published information on wood quality of exotic larch species is limited. In eastern Canada, Fowler and

Table 1. General characteristics of sampled larch plantations

Sample	Location	Species	Mean DBH (mm)	No. of trees	Age[1] (yrs)	Initial spacing/ thinning
1	Maine, USA	European × Japanese hybrid	263	13	22/27	2.3 m×2.3 m/ @age 18, 22yrs
2	Maine, USA	European larch	394	21	63	1.8 m×1.8 m/ @age 41 yrs
3	New Brunswick	Japanese larch	261	25	31	3.0 m×3.0 m/ @age 24 yrs
4	Nova Scotia	European larch	227	15	17	3.0 m×3.0 m/ no thinning
5	PEI	European larch	213	26	34	2.0 m×2.0 m/ @age 25, 31 yrs

[1] Year from planting

his co-workers (1988) have conducted limited wood property tests on a sample of 25-year-old Japanese larch. They also estimated the grade yields of their lumber samples. Keith and Chauret (1988) measured specific gravity, fiber dimensions, extractive contents and lignin content of wood from 23- and 28-year-old European larch. In the United States, Olson *et al.* (1947) conducted a study to determine the strength properties and specific gravity of plantation-grown coniferous woods. A 30 year old European larch plantation was sampled for testing by them. More recently, Isebrands and Hunt (1975) studied specific gravity and extractive content of 10-year old Japanese larch, and Einspahr *et al.* (1983) measured fiber lengths, specific gravity and extractive content of young European larch (18 years), Japanese larch (22 years) and European x Japanese larch hybrid (23 years) as part of a study on pulping characteristics. Where appropriate, wood property results from this study will be compared with the studies listed above.

To summarize, exotic larch species can achieve rapid growth rates in eastern Canada, but only limited data on wood properties is available. This study was conducted to help bridge this gap in information by testing materials sampled from plantations of Japanese, European and European x Japanese hybrid larch grown in eastern Canada and north-eastern United States. The objectives were :

1. To study yields for structural grade lumber.
2. To evaluate bending properties of lumber and clear wood.
3. To evaluate fiber length, specific gravity and cold-water extractive content, and their variations within a tree.
4. To provide an initial indication of how wood properties of exotic larch compared with some commercially important softwood species.

The first two objectives relate to the utilization of the material as structural lumber whereas the third focuses on pulping quality of the material.

Materials and method

Three European, one Japanese and one European × Japanese hybrid larch plantations were selected to provide the test material. These covered a number of geographical locations and a range of age classes. Details about planting spacing, thinning and number of trees sampled are given (Table 1).

After the trees were felled, they were cut into 3.05 m (10 ft) or 3.6 m (12 ft) sawlogs. Each log was coded to indicate the sample location and its position in the tree stem. These logs were transported to the Wood Science and Technology Centre, University of New Brunswick and converted into rough sawn two-by-four lumber pieces at a local sawmill. The lumber was kiln dried to a nominal 12% moisture content, and planed to the final dimensions of 38 mm × 89 mm. The planed lumber pieces were tested for modulus of elasticity (MOE) and modulus of rupture (MOR) in bending according to standard ISO 8375 (ISO 1985). The moisture content, gross specific grav-

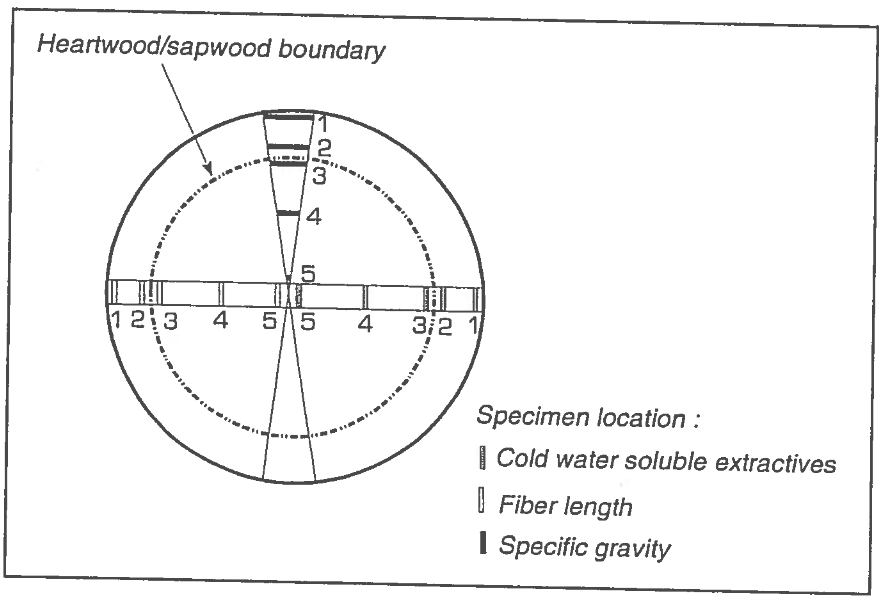

Figure 1. Sampling locations from a disc for fiber length, specific gravity and cold-water soluble extractive content measurements.

Table 2. Yields for selected structural visual grades

Sample	Species/location	No.	Visual grade (%) SS	No.1	No.2	No.3	E	Reject
1	J × E Hybrid, Maine	74	7	36	43	14	0	0
2	European larch, Maine	277	23	42	23	12	1	0
3	Japanese larch, New Brunswick	126	13	55	26	6	0	0
4	European larch, Nova Scotia	47	0	28	72	0	0	0
5	European larch, PEI	76	9	59	32	0	0	0

Table 3. Properties of lumber material

			Lumber bending		Small clear bending				
Sample	Species/location	No.	MOE (MPa)	MOR (MPa)	MOE (MPa)	MOR (MPa)	Specific gravity	MC (%)	Growth rate (mm/ring)
1	J × E Hybrid, Maine	74	7191	30.98	6178	55.12	0.404	13.00	7.31
			(0.29)	(0.29)	(0.25)	(0.18)	(0.10)	(0.07)	(0.28)
2	European larch, Maine	277	10937	43.76	9045	69.62	0.465	13.92	3.58
			(0.28)	(0.36)	(0.19)	(0.14)	(0.097)	(0.05)	(0.38)
3	Japanese larch, New Brunswick	126	8440	39.51	7061	63.29	0.442	12.80	5.77
			(0.29)	(0.30)	(0.24)	(0.21)	(0.09)	(0.05)	(0.28)
4	European larch, Nova Scotia	47	5934	27.26	5187	50.74	0.401	12.43	9.13
			(0.21)	(0.29)	(0.17)	(0.17)	(0.069)	(0.04)	(0.16)
5	European larch, PEI	76	8978	40.53	7431	64.28	0.456	13.30	4.64
			(0.23)	(0.33)	(0.24)	(0.15)	(0.079)	(0.07)	(0.33)

Note : Values shown for properties are means with coefficient of variation given in parentheses

Table 4. Comparison of small clear wood bending properties with corresponding data in the literature

Sample	Species/location	MOE (MPa)	MOR (MPa)	Specific gravity	Reference
1	J × E Hybrid, Maine	6178	51.12	0.404	This study
2	European larch, Maine	9045	69.62	0.465	This study
3	Japanese larch, New Brunswick	7061	63.29	0.442	This study
4	European larch, Nova Scotia	5187	50.74	0.401	This study
5	European larch, PEI	7431	64.28	0.456	This study
6	Norway spruce, New Brunswick	7467	55.09	0.355	Chui, 1993
7	Norway spruce, Nova Scotia	7082	46.61	0.331	Chui, 1993
8	Balsam fir, Canada	9653	58.60	0.356	FPL, 1987
9	Black spruce, Canada	10480	78.60	0.434	FPL, 1987
10	Red spruce, Canada	11032	71.00	0.401	FPL, 1987
11	White spruce, Canada	9998	62.74	0.367	FPL, 1987
12	Norway spruce, USA	9929	58.60	0.356	Olson et al, 1947
13	European larch, USA	6964	58.60	0.356	Olson et al, 1947
14	White spruce, USA	9584	64.81	0.420	Olson et al, 1947

ity and growth rate of each bending specimen were determined from a small prism cross-cut from the specimen. In addition, a small clear (defect-free) specimen of dimensions 38 mm × 38 mm × 610 mm was machined from the undamaged part of each failed lumber piece. The small clear specimen was then tested for MOE and MOR according ASTM D143 (ASTM 1992). The rationale for including the small clear bending test was to provide a common basis for comparison with corresponding properties of other species. In total, 600 pieces of lumber and the same number of small clear specimens were tested.

From the first four plantations, cross sectional discs were obtained from three trees for measurement of fiber length, specific gravity and cold-water extractive content. These trees encompassed the DBH range for the plantation from which they were selected. For each of the three selected trees, a 50 mm thick disc was cut at the stump, 3.0 m and 6.0 m heights for samples one, two and four. For sample three, four discs at stump, 3.6 m, 7.2 m and 11.0 m heights were obtained. The sampling locations for these tests on a disc (Fig. 1) included five measurements from the pith to bark for each property. Three measurements were in heartwood and two in sapwood. The objective was to observe any difference between sapwood and heartwood rather than radial age, particularly with respect to extractive content. The specific gravity was measured based on oven-dry weight and green volume. The method used for determining cold water-soluble extractive content largely followed TAPPI standard T207 OM-88 (TAPPI 1988) with minor modifications. The modifications to T207 OM-88 were introduced to accommodate difficulties in filtering. Fiber length was determined using a common method in which the wood is macerated in an acidic solution and then strained. A computer-based system was used to measure fiber lengths. Lengths of forty randomly selected complete fibers were measured for each sample, and the mean calculated to represent fiber length at each location.

Table 5. Basic wood properties of larch

Sample	Species/location	Fiber length (mm)	Extractive content (%)	Specific gravity
1	J × E hybrid, Maine	3.108 (0.26)	4.45 (0.51)	0.390 (0.11)
2	European larch, Maine	3.845 (0.16)	5.73 (0.63)	0.442 (0.15)
3	Japanese larch, New Brunswick	3.029 (0.20)	6.02 (0.56)	0.441 (0.12)
4	European larch, Nova Scotia	2.783 (0.19)	7.84 (0.48)	0.395 (0.17)

Note : Values shown for properties are means of all readings taken for the sample with coefficient of variation given in parentheses

Table 6. Comparison of basic wood properties with corresponding data in the literature

Species/Location	Age (yr)	Fiber length (mm)	Extractive content[2] (%)	Specific gravity	Reference
J × E hybrid, Maine	22/27	3.108	4.45 (C)	0.390	This study
European larch, Main	63	3.845	5.73 (C)	0.442	This study
Japanese larch, New Brunswick	31	3.029	6.02 (C)	0.441	This study
European larch, Nova Scotia	17	2.783	7.84 (C)	0.395	This study
Japanese larch, USA	22	3.16	7.4 (H)	0.384	Einspahr et al, 1983
European larch, USA	18	3.02	3.90 (H)	0.395	Einspahr et al, 1983
J × E hybrid, USA	23	2.75	4.2 (H)	0.413	Einspahr et al, 1983
Jack pine, USA	55	3.20	2.3 (H)	0.436	Einspahr, et al 1983
Tamarack[1]	–	3.6	–	–	Hatton, 1986
Western larch[1]	–	5.0	–	–	Hatton, 1986
European larch[1]	–	3.6	–	–	Hatton, 1986
European larch, Ontario and Quebec	23/28	2.3	7.99 (H)	0.40	Keith and Chauret, 1988
White pine[1]	–	–	2.1 (H)	–	Hillis, 1962
Douglas fir[1]	–	–	6.5 (H)	–	Hillis, 1962
Red pine, New Brunswick	55	3.09	–	0.380	Kaya, 1990
Japanese larch, USA	10	–	2.0 - 6.0 (H)	0.3 - 0.45	Isebrands and Hunt, 1975

[1] Location and age not known for these samples.
[2] C = Cold-water soluble extractive content, H = Hot-water soluble extractive content

Table 7. Variation of lumber properties with log position in stem[1]

Sample	Species/Location	Log[2]	No.	Lumber bending MOE (MPa)	Lumber bending MOR (MPa)	Small clear bending MOE (MPa)	Small clear bending MOR (MPa)	Specific gravity	MC (%)
1	J × E Hybrid, Maine	1	38	6827 (0.36)	31.04 (0.31)	5772 (0.28)	55.48 (0.18)	0.404 (0.116)	12.98 (0.06)
		2	36	7575 (0.19	30.93 (0.27)	6607 (0.19)	54.74 (0.18)	0.403 (0.089)	13.01 (0.07)
2	European, Maine	1	100	11071 (0.27)	47.28 (0.36)	8783 (0.22)	59.30 (0.16)	0.470 (0.101)	14.19 (0.07)
		2	86	11417 (0.28)	45.12 (0.32)	9434 (0.20)	71.86 (0.11)	0.464 (0.103)	13.84 (0.04)
		3	91	10336 (0.28)	38.61 (0.37)	8964 (0.16)	67.85 (0.13)	0.461 (0.084)	13.70 (0.05)
3	Japanese, New Brunswick	1	73	8256 (0.31)	40.05 (0.31)	7083 (0.27)	65.37 (0.20)	0.448 (0.094)	12.80 (0.05)
		2	53	8693 (0.25)	38.77 (0.29)	7030 (0.20)	60.42 (0.20)	0.434 (0.081)	12.80 (0.04)
4	European, Nova Scotia	1	133	5974 (0.21)	28.73 (0.30)	5102 (0.28)	51.70 (0.16)	0.407 (0.061)	12.42 (0.04)
		2	14	5841 (0.22)	23.79 (0.21)	5386 (0.21)	48.48 (0.19)	0.388 (0.077)	12.45 (0.04)
5	European, PEI	1	45	8878 (0.25)	43.84 (0.33)	7131 (0.27)	6374 (0.17)	0.466 (0.069)	13.28 (0.04)
		2	31	9123 (0 20)	35.73 (0.27)	7866 (0.19)	65.05 (0.13)	0.441 (0.082)	13.33 (0.09)

[1] Values shown for properties are means with coefficient of variation given in parentheses
[2] Log position : 1 = base log, 2 = second log from base, 3 = third log from base

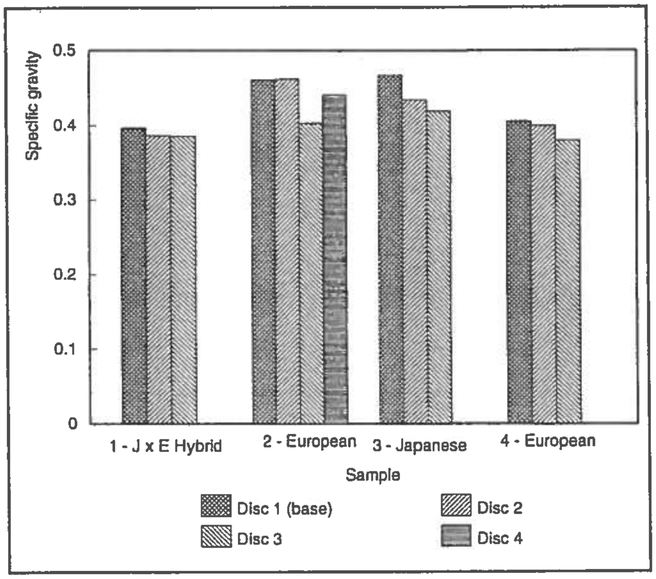

Figure 2. Axial variation of specific gravity.

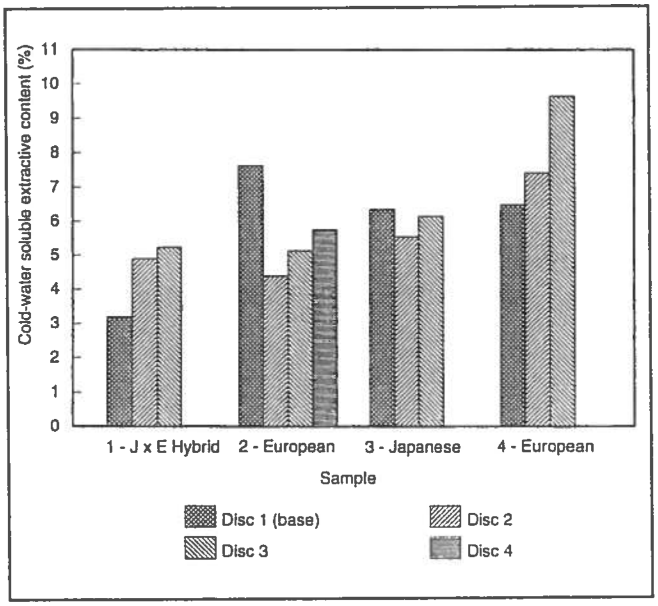

Figure 4. Axial variation of cold-water soluble extractive content.

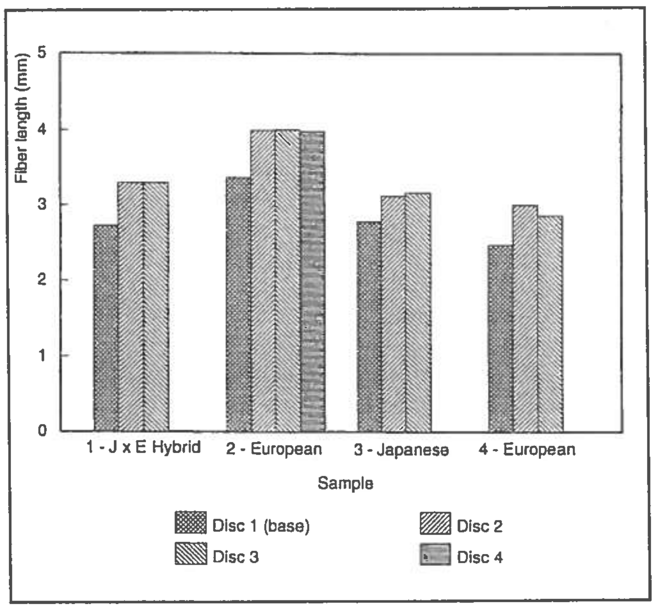

Figure 3. Axial variation of fiber length.

Results and Discussion

Yields for Structural Grade Lumber

Structural grading was performed according to Canadian visual grading rules (NLGA 1987) by a grading inspector from the Maritime Lumber Bureau, Amherst, Nova Scotia. The grades sorted were : Select Structural (SS), No.1, No.2, No.3 and Economy (E). The grade yield results are summarized (Table 2).

Knots are a primary growth feature governing visual grade yields. The presence of knots, their size and distribution, in most cases, determines the grade of a piece of lumber. The size and frequency of knots were relatively large compared with lumber of other native softwood species. This explains the relatively low yields for the SS grade. The grade yields for Japanese larch were, however, better than those obtained by Fowler *et al.* (1988) for the same species. They obtained 45% and 38% yields for No.1 and No.2 grades respectively.

Lumber Properties

The summary statistics for all tested properties are shown (Table 3). When considering mechanical properties it is perhaps not surprising to find that the mature European larch of sample two produced wood with the best quality. Taking into consideration the age and growth rate, it seemed appropriate to compare mechanical properties of samples 1, 3 and 5. The Japanese larch has similar mechanical properties to those of European larch despite a 20% faster growth rate. The European × Japanese hybrid from Maine, USA has somewhat lower mechanical properties, perhaps due to its faster growth rate which led to a lower wood specific gravity.

The small clear bending tests were included to enable a comparison with corresponding properties for other native and exotic softwood species. Such a comparison (Table 4) indicated that MOE and MOR of the mature European larch sample was comparable with those of native balsam fir, white spruce, black spruce and red spruce. Not surprisingly the two juvenile larch samples (1 and 4) had vastly inferior MOE and MOR values. The Japanese larch sample from New Brunswick and European larch sample from PEI had similar MOE and MOR values. Their properties were comparable with plantation grown Norway spruce of similar age from New Brunswick and Nova Scotia (Chui 1993). The larch samples, however, had much higher mean specific gravities than Norway spruce.

Basic Properties of Wood Material

Basic wood properties including fiber length, cold-water soluble extractive content, and specific gravity were determined for samples one, two, three and four. The juvenile European larch from Nova Scotia had a high cold-water soluble extractive content, low specific gravity and short fiber length, indicating that the wood is less suitable for use as pulping material compared with the other samples (Table 5). It must be stressed, however, that this is most probably an age effect rather than a

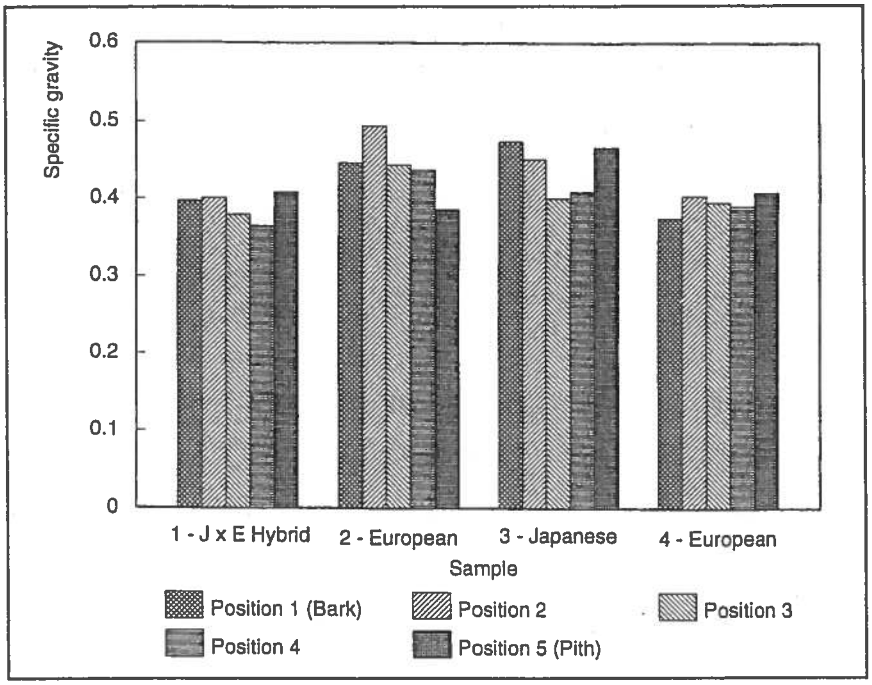

Figure 5. Radial variation of specific gravity.

species effect, as it seems certain that with increasing age fiber length and specific gravity will improve (see sample two). The finding with respect to extractive content is contrary to the previous belief that juvenile wood has lower extractive content because of the small proportion of heartwood in a juvenile stem (Isebrands and Hunt 1975). The extractive content of juvenile wood deserves further study. The other three more mature samples had significantly better wood properties from the standpoint of pulp production.

When comparing these properties with other species (Table 6) it should be noted that the sampling methods differed. For instance, Einspahr *et al.* (1983) measured fiber length at the fifteenth growth ring of three trees, while Kaya (1990) gave the weighted average fiber length for a complete stem based on the readings measured at regularly spaced locations both along the stem and from the pith to bark of one tree. Nonetheless, the quoted values are probably close to the "true" average of the sample tested in each case. Examination of the results shows that, with the possible exception of the juvenile European larch from Nova Scotia, the three measured properties of the tested larch samples were similar to those of some native and exotic softwood species planted in North America. This indicates that substituting traditional softwood species with exotic larch for pulp and paper appears feasible.

Axial Variation of Wood Properties

Mean lumber properties when the results are segregated based on position of test pieces along tree stem (Table 7) showed that the mechanical properties of lumber do not appear to differ along the tree stem. The lack of a clear trend for these exotic larch

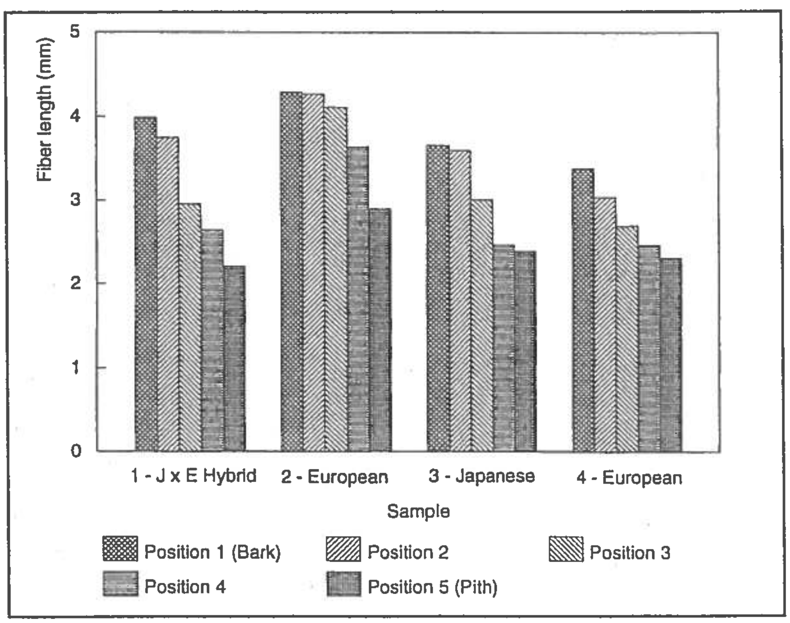

Figure 6. Radial variation of fiber length.

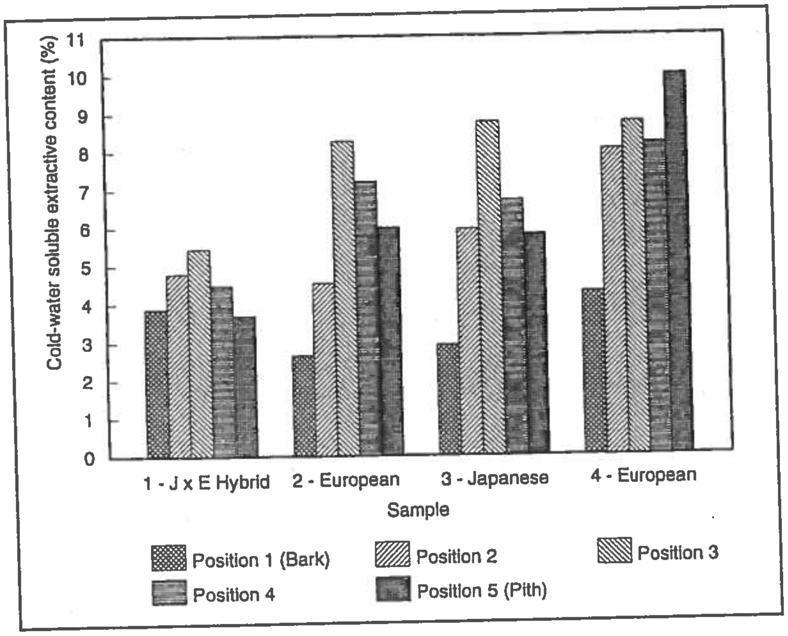

Figure 7. Radial variation of cold-water soluble extractive content.

species is different from that observed for plantation grown Norway spruce (Chui 1993), which showed a very pronounced decreasing trend for mechanical properties with increasing height in the tree stem.

For specific gravity, a trend of decreasing specific gravity with increasing height in a tree stem was noted, with the exception of European larch from Maine (sample two) which showed an increase in specific gravity from disc three to four (Fig. 2). The cause of this slight deviation is not known.

Fibers at stump level (disc one) were shorter than those at higher levels (Fig. 3). No clear differences in fiber length were detected among the other heights. It is not known why this trend occured, but it was similar to results obtained by Keith and Chauret (1988) for European larch. For the cold-water soluble extractive content, the trends were also unclear (Fig. 4). A study by Isebrands and Hunt (1975) on 10-year-old Japanese larch showed that the central part of the base of a tree contained a higher extractive content than other parts of the tree. This agrees with results obtained here for samples two (European larch) and three (Japanese larch), but not with the other two. Thus, further investigations are required if a better understanding of variation in extractive content is desired.

Radial Variation of Basic Wood Properties from the Pith to Bark

The variation of specific gravity from the pith to bark is illustrated (Fig. 5). Each value is an average obtained for all heights. Positions one and five correspond to the locations closest to the bark and pith respectively. There was an initial reduction in specific gravity going from the pith to bark, and then an increase towards the heartwood/sapwood boundary. Afterwards, with the exception of the Japanese larch, a slight drop in specific gravity was observed moving from the heartwood/sapwood boundary towards the bark. This trend belongs to the Type two density variation as defined by Panshin and De Zeeuw (1980), and appears similar to that for European larch tested by Keith and Chauret (1988).

Fiber length clearly increased from the pith to bark (Fig. 6). This was largely due to the shorter fiber length found in the juvenile wood (Larson 1969; Kaya 1990). The ratio of mature to juvenile fiber lengths could be as high as two (sample one). This highlights the problems encountered with the presence of juvenile wood in pulping material. The extractive content results (Fig. 7) showed an interesting trend in which the highest content is found in the heartwood close to the heartwood/sapwood boundary. Again, similar findings were obtained by Keith and Chauret (1988). This phenomenon is probably a result of the large amount of chemicals formed at the early stage of heartwood formation. As expected, extremely low extractive content was found in the sapwood portion.

Conclusions

1. Yields for structural grade lumber of exotic larch species are low because of the size and distribution of knots in processed lumber.
2. Mechanical properties of wood from mature European larch are comparable with corresponding published data for some commercially important native softwood species (e.g. black spruce, white spruce, red spruce and balsam fir). In contrast with most softwood species, no significant axial variation in mechanical properties was observed in this species. The younger larch samples exhibited lower mechanical properties, in comparison with the published data.
3. Fiber length, specific gravity and extractive content of the exotic larch species were similar to published data for some commercially important softwood species, indicating the potential for substituting these exotic larch species with traditional pulping species.
4. Contrary to the common belief, the youngest European larch (age 17) sample had the highest mean extractive content.
5 From the pith to bark the highest extractive content was detected in the newly formed heartwood.

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PULP PROPERTIES OF LARCH KRAFT PULPS

Introduction

Most previous investigations have examined the wood and pulping characteristics of larch of ages in excess of 50 years. Little is known about wood and pulp properties of European, Japanese and/or hybrid larch grown primarily for fiber at rotation ages of 18 to 25 years. Objectives of the larch pulping studies are to determine the usefulness of young (18-25 years) larch in the production of bag and bleachable grade papers. Four sources of larch, including 18-year-old European larch, 23-year-old hybrid larch, 8-year-old hybrid larch and 55-year-old jack pine (control), were pulped separately and in several mixtures of 75% jack pine/25% larch*.

The larch wood chips were investigated for their usefulness as bag paper by cooking to a kappa number of approximately 50 and for use as part of the furnish of bleachable grade pulps by cooking to a kappa number 30. Jack pine was used as a basis of comparison because of its common use in the Lake States and the Northeast. The mixtures selected were used because it appeared that, with the relatively limited supply of larch, the species would not be cooked alone but in mixtures with other conifers and that very likely these mixtures would contain 25% or less of larch. We presently are not advocating the use of material as small or as young as the 8-year-old hybrid larch (U.S. Forest Service), but the material does provide an extreme in wood, fiber and pulp properties that will be useful for comparison purposes.

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*Age 22 Japanese larch is in the process of being pulped in a comparable manner so the results can be integrated into the study described above.

Experimental Materials

The wood chips used in the studies came from three sources of larch and a mill-run source of jack pine. Table XIV summarizes the age, tree size, percent heartwood, and percent compression wood for the four types of material used in the study. The 18-year-old European larch was from a U.S. Forest Service/Wisconsin DNR planting near LaCrosse, Wisconsin. The 23-year-old hybrid larch* was from an Institute planting near Rhinelander, Wisconsin. The 8-year-old trees were part of a U.S. Forest Service intensive management planting near Rhinelander and the jack pine was harvested in northern Wisconsin and came from the Thilmany Pulp & Paper Company's woodpile at Kaukauna, Wisconsin.

TABLE XIV

TREE SIZE AND WOOD QUALITY DATA[a]

Type of Material	Age, yr	Height, feet	Diam., inches	Bark, %	Breast Height, (4.5 feet) Specific Gravity	Breast Height, (4.5 feet) Fiber Length, Age 15, mm	Compression-wood, %	Heart-wood, %
Ripco hybrid larch	24	55.6	7.0	10.1	0.413	2.75	0.4	47.6
European larch	18	54.4	7.6	10.8	0.395	3.02	5.3	46.2
U.S.F.S. hybrid larch	8	21.0	2.0	18.0	0.370	--	12.1	14.9
Jack pine control	55	--	--	--	0.436	--	7.5	28.7

[a]Values based on an average of three trees for the European and Ripco hybrid larch, eight trees for the U.S. Forest Service larch and eight pulpwood bolts for the jack pine.

All materials except the 8-year-old U.S. Forest Service hybrid larch were debarked, chipped and screened prior to pulping. Chips passing the 3/4-inch screen

*22-year-old Japanese larch from this same planting is presently being pulped and evaluated and will be reported on later.

and retained on the 1/2 and the 1/4-inch screens were the fractions that were pulped. The 8-year-old hybrid larch was designated as "whole-tree" chips because the material contained branches and twigs as well as the wood and bark of the main stem. Bark levels were determined to be 23%, on an oven dry basis.

Cooking and Bleaching Conditions

Pulping runs were carried out in a stainless steel vessel of about 72 liters capacity, fitted with external circulation and indirect heating. The chips were charged into a stainless steel basket, which closely matched the interior contours of the digester and which could be removed with the contents following cooking. The cooking liquors were prepared from a solution of sodium hydroxide and sodium sulfide of known concentration and density, together with the appropriate amount of dilution water. The pulping conditions employed are given in Table XV. The pulp was screened through a 0.006-inch cut screen plate in a small Valley flat screen. The rejects were oven dried, weighed and discarded. The accepted fiber was then used to determine the physical properties of the pulps using TAPPI standard methods after beating in a PFI mill at 10% consistency.

TABLE XV

PULPING CONDITIONS

Constant Conditions	
Wood charge, kg o.d.	4.0
Water-to-wood ratio, cc/g	4.0
Effective alkali, % o.d. wood	16.0
Sulfidity, %	25.0
Time to 172°C, min	90
Cooking temperature, °C	172

The kappa 30 pulps were bleached using a CEDED sequence prior to physical property evaluation. Bleaching runs were done using heat sealable polyester bags. Pulp in a crumb form was charged into the bags, diluted with deionized water and the required bleach solution added to give the appropriate bleach consistency. The bleaching conditions and chemical charges employed are shown in Table XVI. Upon completion of the bleaching time, the bag was removed, opened and the sample of pulp removed from the bleaching chemical. The pulp was thoroughly washed and returned to the bag and the remaining steps in the 5-stage bleaching sequence completed in a similar manner. Pulp from the final chlorine dioxide stage was diluted to a 1% consistency and acidified to pH 3 by bubbling SO_2 gas through the pulp suspension to quench any remaining chlorine dioxide activity. Brightness and handsheet strength properties were determined according to TAPPI standard methods.

TABLE XVI

BLEACHING CONDITIONS

Bleach Stage	Bleach Chemical	Chemical Charge, % on o.d. pulp[a]	Consistency, %	Temp., °C	Time, min
1	Chlorine (C)	8.3	3.0	Ambient	45
2	NaOH (E)	4.7	10	70	70
3	Chlorine dioxide (D_1)	1.5	10	60	180
4	NaOH (E_2)	1.0	10	60	60
5	Chlorine dioxide (D_2)	0.5	10	60	180
6	Sulfur dioxide	0.5 to pH 3	1	Ambient	1

[a]Pulp o.d. weight 500 g.

Results and Discussion

Introduction

Space limitations make it desirable to reduce and summarize the many observations and extensive data generated in this study. With such an abbreviated approach, some valuable data must be eliminated. As a partial solution to this problem, the decision has been made to prepare an interim Project 3409 report that would go into greater detail than is appropriate at this time. The interim report would also include results of the Japanese larch pulping work presently under way.

Wood and Fiber Properties

In addition to the wood and fiber properties summarized in Table XIV, which were values based upon disk samples taken at 4.5 feet (breast height), fiber properties of the pulps were measured and this information is summarized in Table XVII.

The specific gravity values for the 18-year-old European larch and the 23-year-old hybrid larch were similar. The jack pine wood samples were higher in specific gravity than any of the larch samples investigated and the 8-year-old hybrid larch had the lowest specific gravity (0.37). The 8-year-old larch also had the highest level of compression wood, suggesting that, if the compression wood had not been present, the specific gravity would have been even lower.

The pulp fiber dimensions summarized in Table XVII were surprisingly similar for the several sources of larch and larch/jack pine mixtures. Fiber length of the European larch and 8-year-old hybrid larch appeared to be slightly less than the other pulps. Also, the fiber width and coarseness of this relatively young material appeared to be lower than the other pulps evaluated. Most of the values given in Table XVII are consistent with the exception of the coarseness of the hybrid larch/jack pine mixture involving the 23-year-old larch. These values were lower than anticipated and the results will be rechecked. In the samples evaluated, lower wood density was associated with the lower fiber coarseness. Also of interest was the similarity in coarseness between the jack pine control pulps and the two older sources of larch.

TABLE XVII

PULP FIBER DIMENSIONS

Type of Material	Fiber Length, mm		Fiber Width, µm	Cell Wall Thickness, µm	Coarseness, mg/100 m	Kappa No.
	Arith.	Weighted				
Ripco hybrid	1.7	2.2	46.7	5.5	24.6	53.4
larch	1.7	2.2	47.7	5.1	21.2	34.6
European larch	1.6	2.1	44.3	5.1	24.6	52.7
	1.6	2.0	45.8	4.7	17.5	31.4
U.S.F.S. hybrid larch	1.6	2.1	40.6	4.6	18.0	54.8
Jack pine	1.9	2.2	42.1	4.5	22.0	51.1
control	1.9	2.3	44.3	5.7	20.5	34.4
25% Hybrid larch/	1.9	2.3	40.3	5.3	15.7	52.2
75% jack pine	2.1	2.5	44.2	5.1	17.6	31.1
25% European larch/	1.9	2.4	42.2	4.6	19.3	49.5
75% jack pine	1.9	2.3	42.7	4.4	20.8	29.4
25% U.S.F.S. hybrid	1.7	2.2	39.9	5.5	21.3	51.6
larch/75% jack pine	1.7	2.2	42.3	4.6	19.1	34.2

Wood Chemical Comparisons

Pulp yields are related to cooking conditions and lignin and extractive levels in the original wood samples. Table XVIII summarizes this information for the four sources of experimental chips. All sources had similar levels of lignin and the three sources of larch were similar in levels of alcohol-benzene extractives and lower than jack pine in this property. Hot-water extractives, in contrast, were higher for larch than jack pine and the 8-year-old hybrid larch had the highest level (7.4%), presumably because of the high levels of bark (23%). The lower pulp yields of the 8-year-old larch described in the section that follows reflects the lack of fibers in the bark and the high extractive levels. It should, however, be pointed out that hot-water extractive levels reported for the 18- and 23-year-old larch were about 1/2 the levels found in the literature for older larch.

TABLE XVIII

CHEMICAL PROPERTIES OF WOOD

Type of Material	Lignin, %	Extractives, % Alcohol-Benzene	Extractives, % Hot Water
Ripco hybrid larch	27.94	2.47 --	4.18 --
European larch	27.60	1.80 --	3.90 --
U.S.F.S. hybrid larch	--	2.40	7.39
Jack pine control	27.45	3.54 --	2.31 --

Pulp Yields

The pulping procedure followed was to establish the goals of kappa number* 50 (bag papers) and 30 (bleachable pulps) and then vary cooking conditions (H-factor) to obtain pulps that could be used in pulp strength comparisons. Table XIX summarizes these results. It should be noted that the 100% 8-year-old hybrid larch was not cooked to kappa 30 because it didn't seem appropriate in view of the high levels of bark (23%).

The pulp yield information provided several interesting results. Comparing unscreened pulp yields**, for example, consistently demonstrated a 3-4% yield advantage for the 18- and 23-year-old larch over the 55-year-old jack pine. The lowest

*Kappa number reflects the lignin remaining in the pulp.
**Even though rejects are high for the 100% European and the 100% 23-year-old hybrid larch, in practice, these fibers would be returned to the digester and pulped further and the fiber not lost.

yield resulted from the pulping of the 8-year-old hybrid larch (36.3%) and presumably reflects the effect of the high levels of bark, compression wood and juvenile wood.

TABLE XIX

PULPING DATA

Composition	Factor	Kappa No.	Unscreened Yield, % o.d. wood	Screened Yield, % o.d. wood	Screened Rejects, % o.d. wood
100% Jack pine	1850	34.4	43.8	43.2	0.6
	1450	49.2	47.1	46.2	0.9
25% European larch	1850	29.4	47.1	46.5	0.6
	1350	54.4	47.9	47.0	0.9
100% European larch	1850	31.4	47.1	46.8	0.3
	1200	52.7	51.1	40.1	11.0
25% Hybrid (23 yr) larch	1850	31.1	46.6	46.1	0.5
	1350	52.2	49.7	46.8	2.9
100% Hybrid (23 yr) larch	1850	34.6	48.5	47.1	1.4
	1200	53.4	51.8	41.5	10.3
25% Hybrid (8 yr) larch	1900	34.2	46.3	44.8	1.5
	1600	51.6	48.4	46.3	2.1
100% Hybrid (8 yr) larch	1800	54.8	36.3	35.3	1.0

Equally important is compatibility of the jack pine and the 18- and 23-year-old larch to cooking conditions when cooked either alone or in mixture. Figure 14 illustrates this relationship and suggests all sorts of larch/jack pine mixtures could be cooked together without complications. In contrast, the 8-year-old hybrid larch chips with high levels of bark and compression wood were more difficult to cook alone and also required more severe cooking conditions when cooked as a 25% larch/ 75% jack pine mixture.

Kappa 50 Pulp Strength

Table XXIII of the Appendix summarizes the physical properties of unbleached kappa 50 pulp. Figures 15 through 18 illustrate a number of important strength property interrelationships. Figure 15 illustrates the amount of beating required to reach a given breaking length and demonstrates the differences which exist between the pulps in terms of maximum attainable breaking length. It is apparent that European larch, both alone and in the mixture with jack pine, beats at a rate similar to pure jack pine. The hybrid larch, both 8-year-old and 23-year-old, were consistently more difficult to beat and attained significantly lower maximum tensile strength. The beating characteristics and maximum breaking length values of the 25% larch/75% jack pine were similar to that of the pure jack pine, particularly for the European larch/jack pine mixture.

The 8-year-old hybrid larch was the most difficult to beat and attained the lowest maximum breaking length. The juvenile nature of the fibers and the percent compression wood are believed to be factors involved. Photomicrographs (U.S.F.S.) taken at various beating levels demonstrated that, at low beating levels, a fairly dense, well-bonded handsheet of collapsed fibers was formed and additional beating did not improve the situation. The lower zero-span tensile values (Appendix Table XXIII) suggest lower fiber strength (juvenile and compression wood) may also be involved.

Another useful way to compare pulps is to plot tear factor versus breaking length. This approach assumes the pulps are beaten to improve breaking length and, with increased beating, there will be a tearing strength loss. The better pulps are those that attain good breaking length (9-11 km) and retain tear factor values of 120 or more. Figure 16 illustrates such a comparison for the pulps involved in this study. The 8-year-old hybrid larch and the mixture of this hybrid and jack pine had lower strength values, while the 23-year-old hybrid larch, the 18-year-old European larch and the 25% larch/75% jack pine mixtures appeared to be comparable and had better tear/breaking length strength properties than pulps containing the 8-year-old "whole tree" pulps.

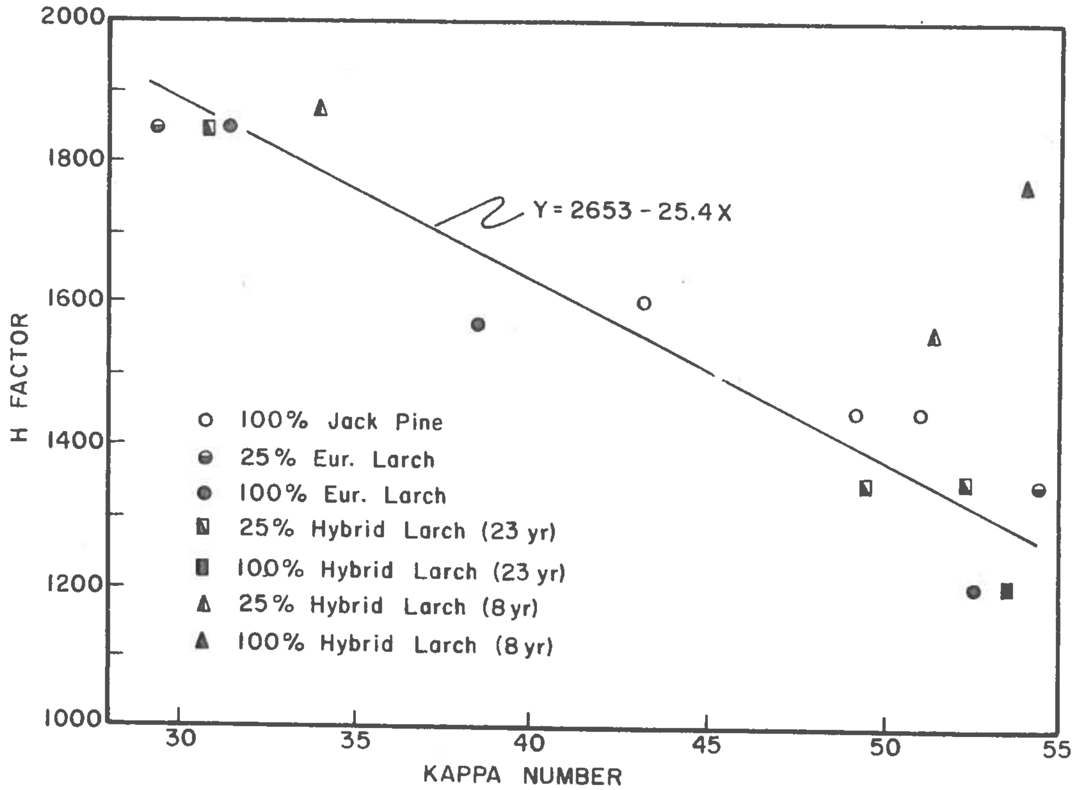

Figure 14. H-Factor Requirements vs. Kappa Number

Plotting burst factor vs. breaking length (Fig. 17) and apparent density vs. breaking length (Fig. 18) indicated that the pulps behaved in a manner typical of most conifers and that there were no important differences between the pulps evaluated.

Kappa 30 Bleaching Results

Literature describing pulping of older-aged larch often described bleaching problems. The bleaching characteristics of the kappa 30 pulp were investigated using the previously described bleaching procedure. Table XX describes the use of a CEDED bleaching sequence. The bleached pulps produced were then evaluated for strength

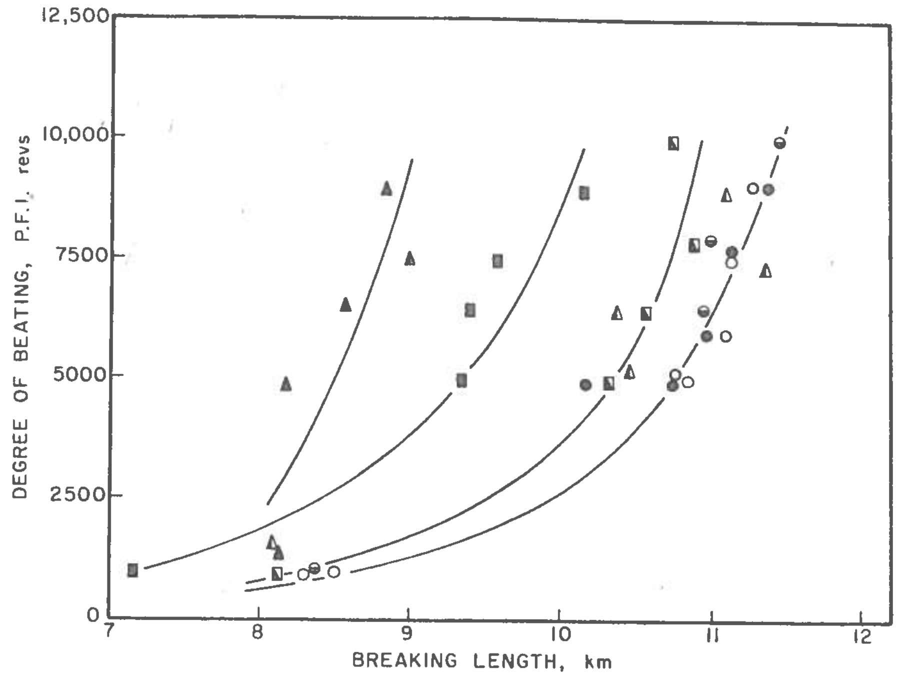

Figure 15. Degree of Beating Required vs. Breaking Length, Kappa 50 Pulps

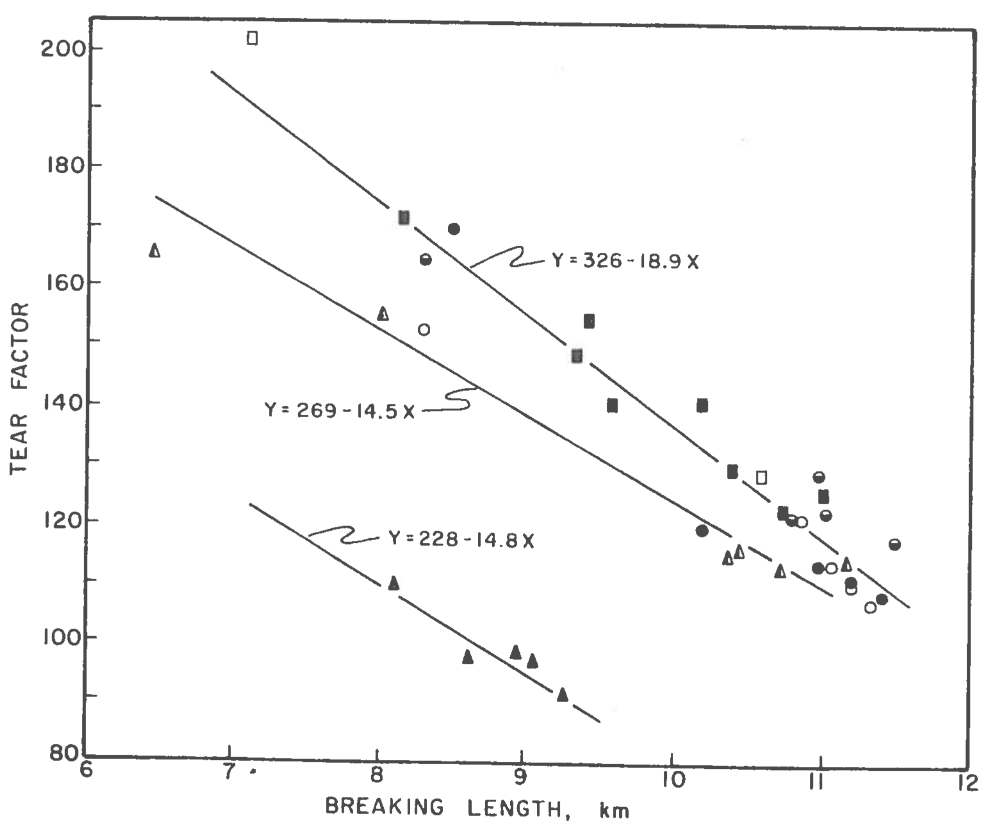

Figure 16. Tear Factor vs. Breaking Length, Kappa 50 Pulps

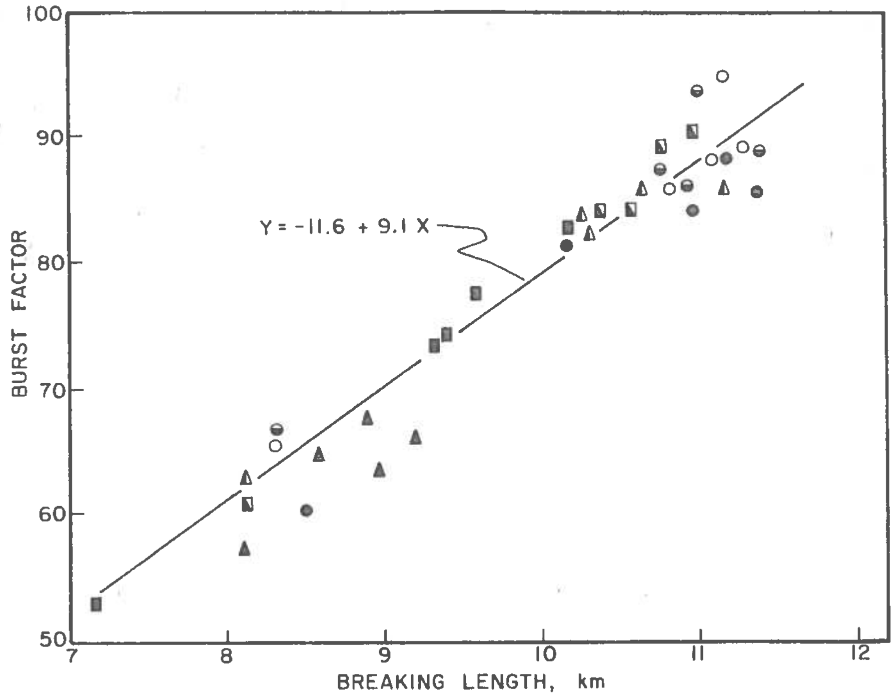

Figure 17. Burst Factor vs. Breaking Length, Kappa 50 Pulps

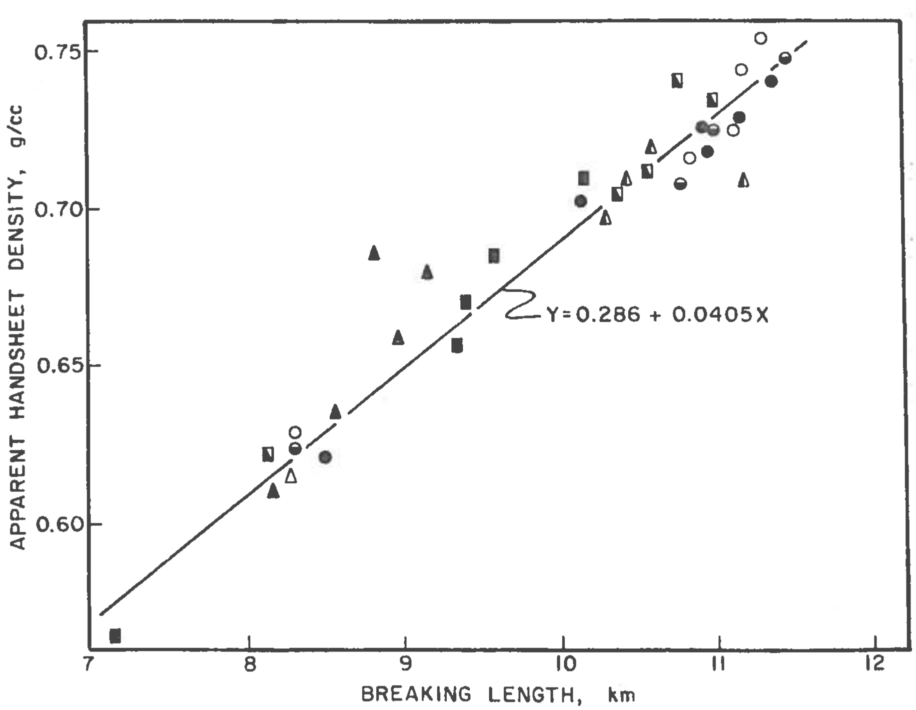

Figure 18. Apparent Handsheet Density vs. Breaking Length, Kappa 50 Pulps

TABLE XX

BLEACHING RESULTS OF 30 KAPPA PULPS

Wood Type	Chlorination Stage (C_1) % Cl_2 Consumed on o.d. pulp	Extraction Stage (E_1) Permanganage No. (25 mL)	Extraction Stage (E_1) End pH	Chlorine Dioxide Stage (D_1) % ClO_2 Consumed on o.d. Pulp	Extraction Stage (E_2) End pH	Chlorine Dioxide Stage (O_2) % ClO_2 Consumed on o.d. Pulp	G.E. Brightness, %
100% Jack pine	7.0	5.2	12.0	1.20	10.5	0.4	90.3
100% European larch	7.3	5.3	12.2	1.44	10.9	0.4	88.2
100% Hybrid (23) larch	7.0	5.7	12.2	1.32	11.3	0.21	88.3
75% Jack pine + 25% European larch	7.2	4.9	12.3	1.28	10.8	0.25	89.5
75% Jack pine + 25% hybrid (23) larch	7.0	4.6	12.7	1.27	10.4	0.23	90.2
75% Jack pine + 25% hybrid (8) larch	8.3	5.9	12.4	1.38	12.3	0.20	84.6

properties. The pulps from the two older sources of larch and the pulp from mixtures of the older larch with jack pine attained appropriate brightness levels and had similar chemical consumption as the jack pine control pulp. The pulp mixture of the 25% 8-year-old larch/75% jack pine had higher first-stage chlorine consumption and a lower final brightness.

Kappa 30 Pulp Strength Properties

The kappa 30 bleached pulps were evaluated using procedures similar to those used for the kappa 50 pulps. Appendix Table XXIV summarizes these evaluations. The kappa 30 pulp reacted to beating in a similar manner and developed similar strength as the kappa 50 pulps. Figure 19 illustrates the breaking length beating requirements. The European larch and jack pine behaved, as with the kappa 50 pulps, in a very similar manner. The 23-year-old hybrid and the two 25% hybrid larch/75% jack pine mixtures also reacted to beating in a manner similar to the jack pine bleached pulp. This appears to have occurred because, as the result of cooking to kappa 30 and bleaching, additional lignin was removed.

Removing greater amounts of lignin reduced inherent differences between fiber sources and, as a result, they reacted to refining in much the same way. Figures 20 through 22 confirm that the bleached kappa 30 pulps tended to respond to refining in a similar manner. Scattering coefficient measurements are related to bonding (lower values equal greater bonding). Figure 23 compares the response of the several pulps in terms of scattering coefficients <u>versus</u> beating and further substantiates the similar nature of the kappa 30 bleached pulps.

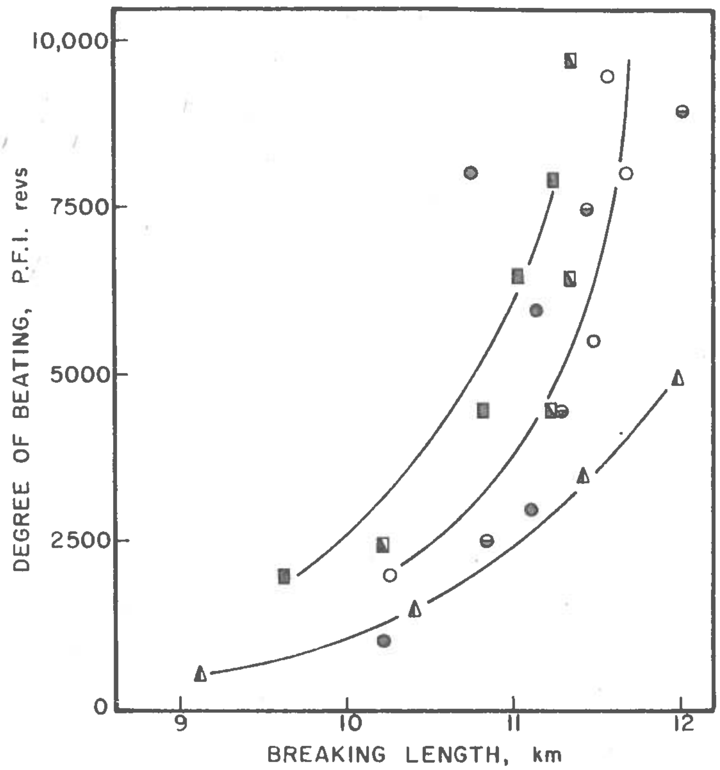

Figure 19. Degree of Beating Required vs. Breaking Length, Kappa 30 Bleached Pulps

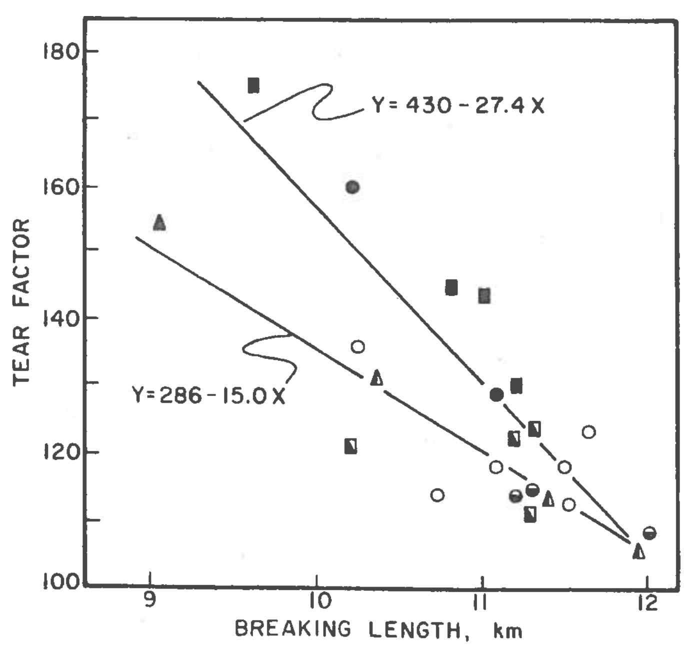

Figure 20. Tear Factor vs. Breaking Length, Kappa 30 Bleached Pulps

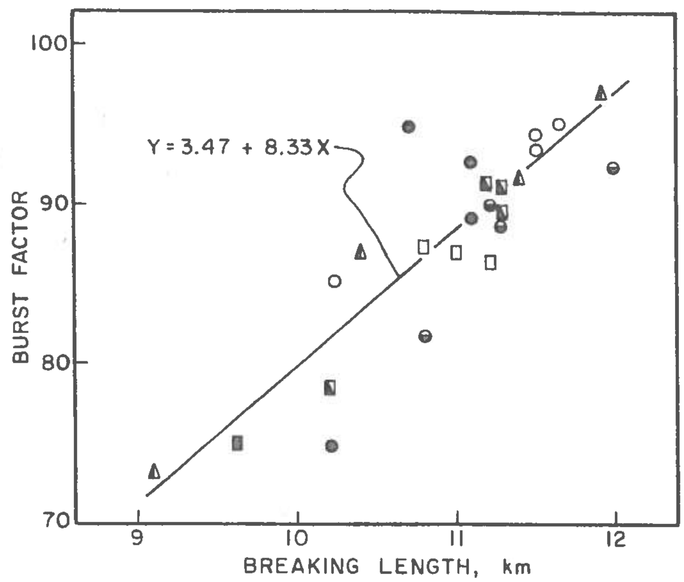

Figure 21. Burst Factor vs. Breaking Length, Kappa 30 Bleached Pulps

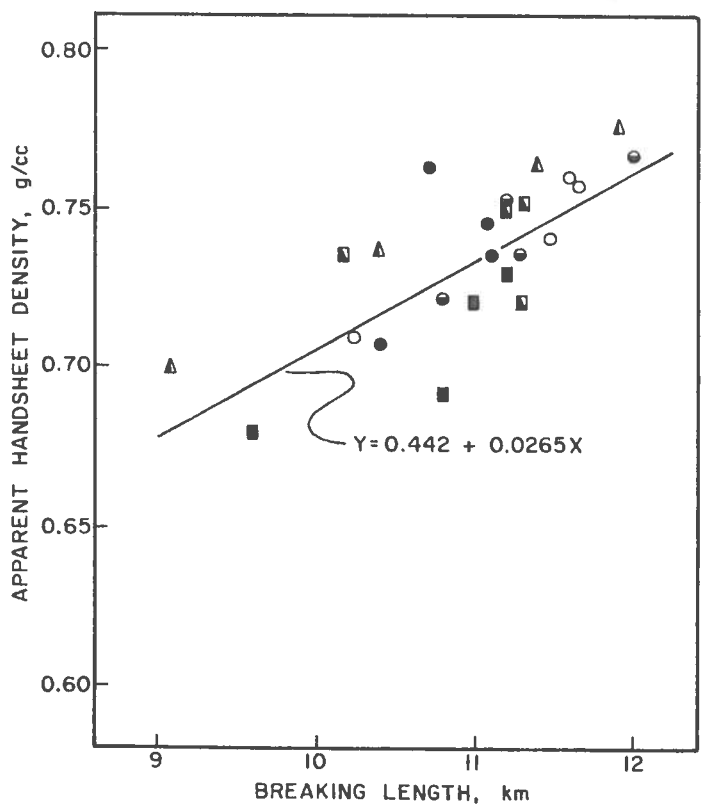

Figure 22. Apparent Handsheet Density vs. Breaking Length, Kappa 30 Bleached Pulps

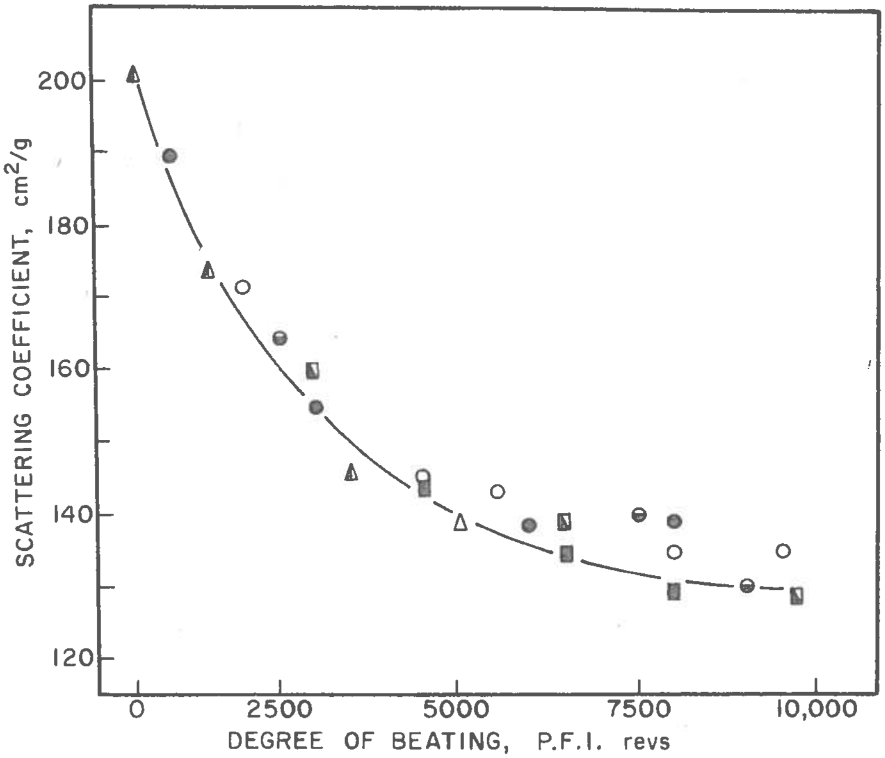

Figure 23. Scattering Coefficient vs. Degree of Beating

Strength Properties of Kappa 30 Bleached Pulp/Hardwood Pulp Mixtures

To evaluate the relative usefulness of the bleached kappa 30 pulps in improving the properties of bleached hardwood pulps, the following mixtures were prepared and evaluated:

Symbols

O	50% bleached jack pine + 50% bleached hardwood pulp
□	50% bleached European larch + 50% bleached hardwood pulp
△	50% bleached hybrid larch (23 yr) + 50% bleached hardwood pulp
■	50% bleached jack pine/European larch mixture + 50% bleached hardwood pulp
▲	50% bleached jack pine/hybrid larch (23 yr) mixture + 50% bleached hardwood pulp
X	50% bleached jack pine/hybrid larch (8 yr) mixture + 50% bleached hardwood pulp

Appendix Table XXV summarizes the results of these comparisons and Fig. 24 through 27 illustrate the reaction of these pulp mixtures in terms of strength properties and bonding (scattering coefficients) to refining. All of the bleached conifer/bleached hardwood mixtures responded in a similar manner with the exception of the mixture containing the 8-year-old hybrid larch pulp. This pulp was better bonded than the other pulps (when compared at comparable levels of beating and/or handsheet density) but had lower tearing strength at comparable breaking length levels.

Summary

Kappa 50 pulps for use as bag papers and kappa 30 pulps for bleached grade pulps were produced by pulping European larch, two sources of hybrid larch and jack pine control chips along with several 25% larch/75% jack pine mixtures. Standard TAPPI methods were used in evaluating the pulps. The results are summarized as follows:

1. The larch chip sources and the mixtures with jack pine cooked at similar or slightly faster rates than jack pine.
2. Unscreened yields, except for the 8-year-old, whole-tree chips, were 3-4% higher for larch than jack pine. Pulp yields of the larch/jack pine mixtures reflected the presence of larch in the mixtures.
3. Unscreened yields of kappa 50 pulps from the 8-year-old hybrid larch whole-tree chips were about 11% lower than the bark-free jack pine chips.
4. Cooking larch chips to kappa number 50 resulted in large quantities of screen rejects that were eliminated by cooking to kappa number 30.

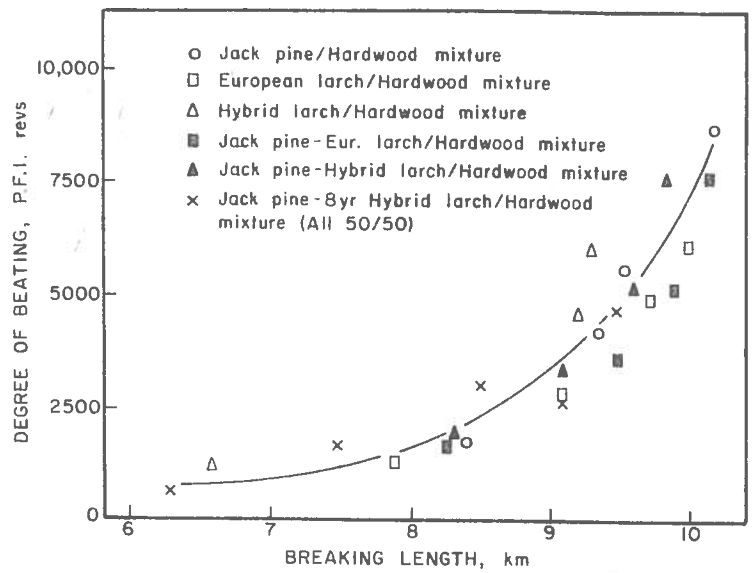

Figure 24. Degree of Beating vs. Breaking Length, Bleached Conifer/Bleached Hardwood Pulp Mixtures

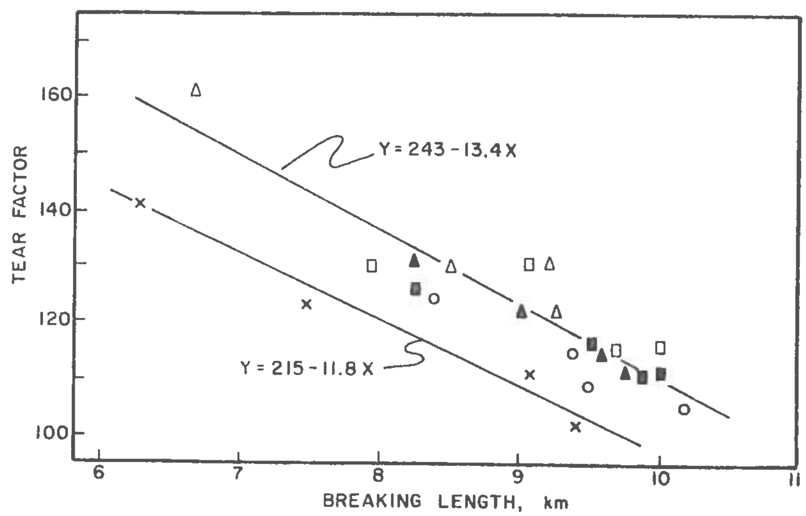

Figure 25. Tear Factor vs. Breaking Length, Bleached Conifer/Bleached Hardwood Pulp Mixtures

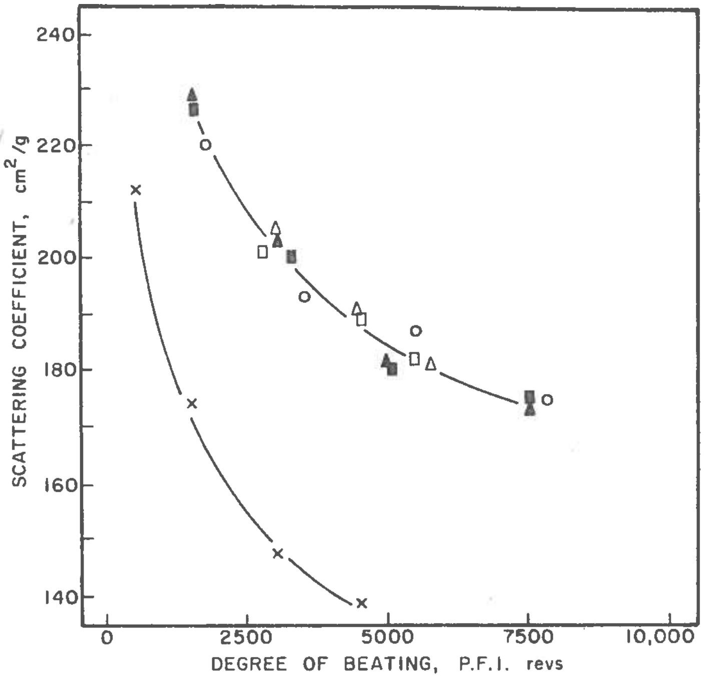

Figure 26. Scattering Coefficient vs. Degree of Beating, Bleached Conifer/Bleached Hardwood Pulp Mixtures

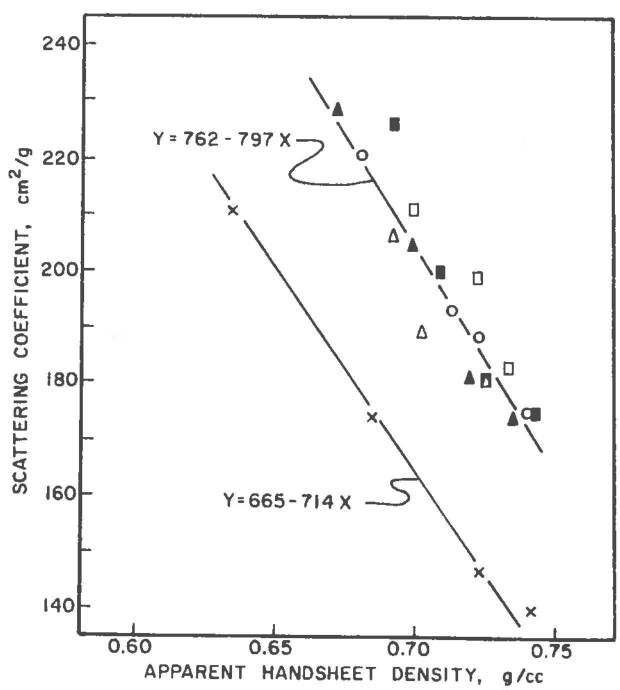

Figure 27. Scattering Coefficient vs. Apparent Handsheet Density, Bleached Conifer/Bleached Hardwood Pulp Mixtures

5. The kappa 50 pulps of the 23-year-old hybrid larch and the 8-year-old hybrid larch were more difficult to beat and developed lower ultimate breaking length than the European larch, jack pine and the 25% larch/ 75% jack pine mixtures.
6. The kappa 50 pulps from the 8-year-old hybrid larch and the mixtures with jack pine had lower tear and the lowest ultimate tensile strength. Tearing strength of the European larch and the 23-year-old hybrid larch was slightly higher than jack pine at the same breaking length.
7. The bleachability of the larch pulps was similar to the jack pine control pulps, with the exception of the pulp mixtures involving the 8-year-old hybrid larch and jack pine, which was more difficult to bleach.
8. Pulping larch and larch/jack pine mixtures to a kappa 30 followed by bleaching resulted in pulps that had strength properties that were very similar to the jack pine control. Only the 8-year-old hybrid larch/ jack pine mixture had lower tear as the result of refining to develop breaking length.
9. When bleached larch and bleached larch/jack pine pulps were mixed with bleached hardwood pulps, the strength properties were comparable to the strength of pulps prepared from bleached jack pine/bleached hardwood pulp mixtures. The only exception was the bleached 8-year-old hybrid larch-jack pine/bleached hardwood pulp mixture. This mixture had lower scattering coefficient and lower tear than the other pulp mixture.